

Computer Modeling of Atrial Defibrillation

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Abstract

Atrial fibrillation (AF) is a condition that affects 2,000,000 people per year in the US alone. Treatment for AF is either drug therapy or defibrillation with a strong electric shock. In the past, clinical data has not agreed on which electrode position is the most effective to successfully defibrillate the atria. The objective of this study is to determine the optimal placement and size to defibrillate the atria with minimal energy.

METHODS: *A placement was considered to be the most effective if it maximized the current that was delivered to the atrial tissue. Using a three dimensional finite element model of the human torso, 38 different placements of pairs of nodes on the torso were divided into three configurations (12 pectoral, 14 anterior-posterior, 12 anterolateral) and tested to determine the required voltage needed to successfully defibrillate 95% of the atrial tissue (DFT). Keeping the best placements for each configuration constant, four realistic electrode sizes (13, 50, 106, 132 cm²) were tested to determine which size delivered the most current to the atrial tissue.*

RESULTS: *The 132 cm² electrode produced the lowest DFT for all 3 configurations. The computed DFTs for this size were 252, 288, and 368 V for the pectoral, anterior-posterior, and anterolateral configurations, respectively.* **CONCLUSIONS:** *Our model suggests that the commonly used clinical electrode placements or sizes may not be the optimal configurations to defibrillate with minimal energy.*

1. Introduction

1.1 Atrial Fibrillation

Atrial fibrillation is a potentially life threatening condition that affects about two million people per year in the US alone [1]. It is composed of wavelets of electrical activity that continue to rush quickly across the atria causing to it fibrillate at a rate between 300 to 600 times a minute.

Though AF is not immediately life threatening, it increases the chances for other conditions to occur. When the blood in the atrium ceases to flow steadily, it begins to clot. The clot could enter the bloodstream and become lodged in an artery that leads to the brain, causing an embolic stroke.

1.2. Defibrillation

Present day treatments for inducing cardioversion for AF consists of drug therapy and external defibrillation. Defibrillation is an electrical shock given to the body to induce cardioversion of the heart tissue. Typically 2 electrodes are used with a shock value between 40-360J [2-8]. The shock value needs to exceed the defibrillation threshold (DFT) for it to be successful. In this study DFT is defined as the voltage required to raise 95% of the tissue above 5 V/cm.

In about 30% of people who have AF, maximum external energy defibrillation shocks are unsuccessful [9]. This poses the need to use invasive catheters. Higher energy shocks are known to cause burns at the electrode sites, which studies have shown may lead to damage of heart tissue [4]. For these reasons, it is preferred and the most simple to use external electrodes.

1.3 Objective

The main purpose of this study is to determine the optimized electrode placement for external defibrillation using a physiologically realistic computer model of a human thorax. The purpose of determining an optimized placement and size is to help minimize the need for invasive catheters and minimize the shock strength on the initial shock. If the first shock given to a person is optimized, the number of future shocks that might be needed will also be minimized.

2. Methods

2.1 Model

A physiologically realistic three-dimensional finite element model of the human thorax was used to calculate the defibrillation thresholds and the potential gradients throughout the atrium [10]. Data was input into the program that described the placement of the nodes along the surface of the model and the voltages associated with each one. The model contains: body surface, skeletal muscle, lungs, epicardium, left atrium, right atrium, left ventricular endocardium, right ventricular endocardium, aorta, superior vena cava, and pulmonary trunk.

The model was initially developed from 90 sequential magnetic resonance images (MRI) taken 5mm apart. Organs and tissues of interest on the MRIs were traced and digitized on a computer. Nodes were spaced equidistant along the perimeter of each tissue. The nodes were then triangulated to create surfaces for each of the tissue types. Surfaces were then incorporated into the model with 3-D tetrahedron volume elements.

2.2 Conductivities

Each tissue was assigned an appropriate conductivity. Table 1 shows all of the conductivities for each type of tissue used. All tissues were assumed to be isotropic, which means that the conductivity is assumed to be the same in all directions throughout a homogeneous material [11].

Table 1. Tissue Conductivities

Tissue Type	Conductivity
Lungs,	0.78 mS/cm
Blood	6.67 mS/cm
Myocardium	2.50 mS/cm
Connective Tissue	2.22 mS/cm
Skeletal Muscle	2.50 mS/cm

2.3 Electrode Configuration

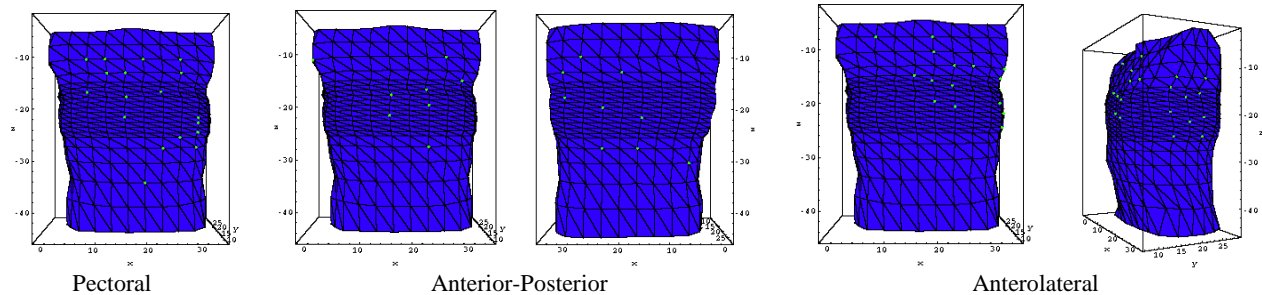


Figure 1. Node placements used for each configuration

Electrode placements and sizes tested in this study were based on present clinical studies [2-8]. Several non-clinical placements were also used. The method used for choosing the non-clinical placements requires that a straight line drawn between the two nodes intersect over where the atria are located. A total of 38 node pairs were chosen on the thorax and broken into three electrode configurations as follows: 12 pectoral (PC), 14 anterior-posterior (AP), and 12 anterolateral (AL). Figure 1 shows the various nodes tested for optimal placement. Each of the placements consisted of two infinitely small nodes and tested to determine the DFT.

After a best node pair is found for each configuration, the placement will remain constant so that the effects of varying electrode size can be studied. Four realistic electrode sizes were found to be presently used in a clinical setting. The sizes consisted of the following surface areas: 13, 50, 106, 132 cm² [2-8]. Three criteria were considered when designing the layout of the electrodes. The first criterion is that the electrode had to be symmetrical. The second criterion is that the geometric center of the electrode must correspond with the optimal node pair discovered from the first half of the testing. The third criterion is that the surface area must be approximated as close to the needed value as possible.

3. Results

The node pair that had the lowest DFT for each configuration was determined and then used to test the effect of electrode size. The DFTs calculated for all for the initial 38 node pairs varied for each configuration. The range for each setup is as follows: 883-3267V (PC), 1101-2533V (AP), and 1523-3137V (AL). Table 2 shows the calculated DFTs for each electrode size for the optimal placement for each node pair. The best size for each configuration was found to be 132 cm.

Table 3. DFT's for each electrode size in optimal placement

	13 cm ²	50 cm ²	106 cm ²	132 cm ²
PC	439 V	313 V	264 V	252 V
AP	481 V	380 V	301V	288 V
AL	693 V	455 V	404 V	368 V

The best overall placement and size found was the pectoral configuration of two 132 cm² electrodes. More specifically, the placements of the electrodes were located at the proximal end of the sternum and about 5-6 cm below the distal end of the sternum. Figure 2a shows the anterior surface of the thorax and two sets of nodes. The green pair is the standard placements currently used in clinical experiments. The pink pair of nodes is the set that was discovered to be the best by the model. Figure 2b shows the arrangement of the appropriate electrode on the body in the position best chosen by the model. Table 3 shows the comparison of the DFT's of the standard node pairs with the ones chosen by the model.

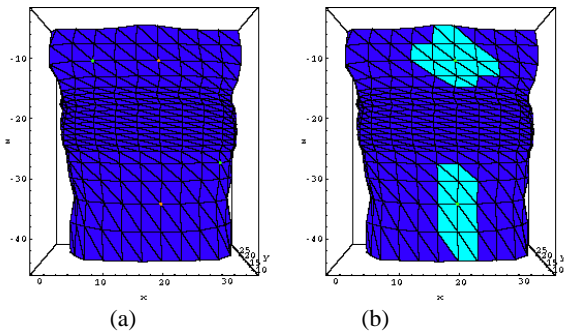


Figure 2a. Torso showing standard placements and placements chosen by model. (b) Electrode layout for most optimal placement and size.

Table 3. Standard DFTs vs. Model DFTs

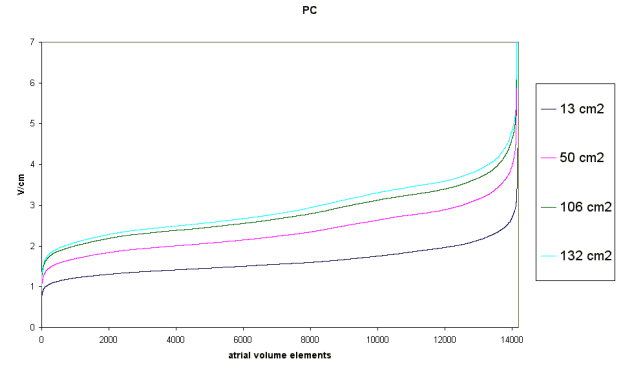
	Standard	Model
PC	1260 V	883 V
AP	1249 V	1101 V
AL	1725 V	1523 V

4. Discussion

Only one independent variable can be varied at one time to effectively interpret the results. The study was simplified to use only 2 electrodes, even though the

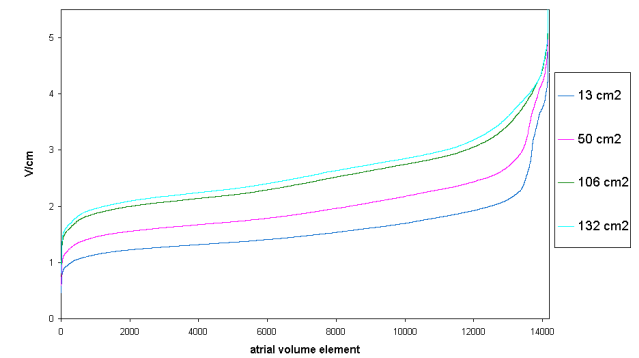
model was capable of simulating defibrillation using any number of electrodes.

The results show that the potential gradient field increases in the atria as the electrode size increases.



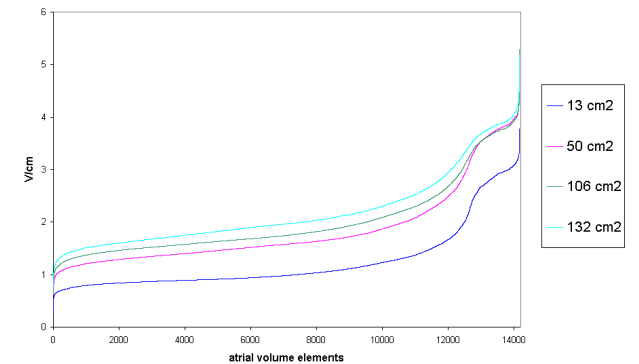
(a)

AP



(b)

AL



(c)

Figures 3a-c. Potential gradients throughout the atria for each configuration and electrode size.

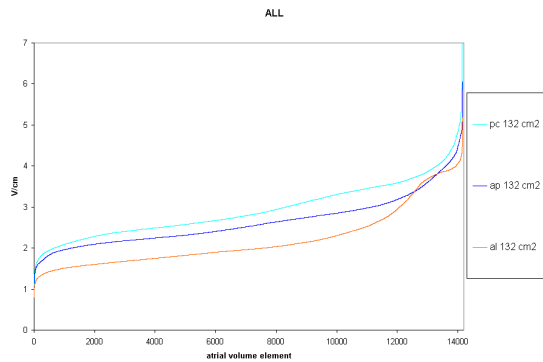


Figure 4. Potential gradients found throughout the atria for the optimal sizes for each configuration

Though the exact rate of change of potential gradient to electrode size is unknown, it seems as if the gradient values will continue to converge to a particular distribution resulting in an absolute optimized size. If the size were to increase beyond this optimized size, it should have no significant effect on the gradient. Figure 4 shows the relationship between all of the best electrode sizes for all configurations for overall comparison.

There were several limitations to this study. The model consisted of closely spaced electrodes around the surface of the thorax where the heart was located. As the nodes moved outward from the middle, the resolution dropped. This caused problems when designing the electrodes because the electrodes could not be exactly symmetrical. This also posed a problem for the electrodes in the low-resolution triangles. The larger the triangles, the less accurate the surface area comes to being the desired value. There was no external fat layer considered in the model, which might have altered the results. This model was also static, which means that no dynamic waveforms could be tested. Nevertheless, which ever placement and size that were calculated from the model, a biphasic waveform can be considered to defibrillate with a lower energy than the monophasic one tested.

Our model suggests that the commonly used clinical electrode placements and sizes may not be the optimal configurations to defibrillate the atrial tissue with minimal energy. At the very least, a standard electrode size needs to be established so that any error in placing the electrodes can be minimized. Therefore more testing is needed in order to determine any optimal configurations or methods.

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